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Keywords: Calcareous mudstone; Soil properties; Taxonomic Classification; Nutrients

## Introduction

Calcareous mudstone is a sedimentary rock and consolidated product of calcareous sands, limy mud and crushed shells (Anatale, 1996). It is composed of carbonates in the form of aragonite, calcite and dolomite (Wicander, 1995). The mudstone formations have been referred to as River Shale group or the oldest marine carbonate sequence which are mostly impervious shale with

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## **Characterization, Classification and Micronutrients contents of three Pedons overlying Calcareous Mudstone in a Tropical Rainforest of Nigeria**

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### **Abstract**

Soils overlying calcareous mudstone in the tropics have peculiar characteristics and are rarely studied. The study was designed to evaluate the soils based on their morphological, physical and chemical properties, and relate these properties with soil micronutrients. The soils were also taxonomically classified using the USDA Keys to Soil Taxonomy. Correlation analysis and descriptive statistics were adopted in the interpretation of data using the R software. The contour map of New Netim was generated in the ArcGIS 10.8 environment and the profile graph plotted out. One profile pit was sunk along each elevation range using free survey technique, to represent soils in the highest (P1), mid (P2) and lowest (P3) elevations. The fairly deep to deep soils (60-163 cm) were loamy in texture with the dominance of silt and sand over clay, and low bulk density (1.2-1.6Mg<sup>3</sup>/m). Soil pH (HQ) ranged from 7.1 to 8.04, while organic C and total N were 0.49-2.41 and 0.01-0.21%, respectively with values that regularly decreased with increased soil depth. The soil cation exchange complex was dominated by Ca<sup>2+</sup> (7.02-61.0 cmol/kg) and Mg<sup>2+</sup> (0.4-17.7 cmol/kg), while base saturation was > 50 %. Available Fe, Mn, Cu, Zn and B were less than their respective world-wide agricultural and environmentally acceptable values with ranges of 94.8-162.3, 21.5-159.8, 1.8-3.31, 2.6-4.8 and 1.6-2.34 mg/kg, respectively. CEC and exchangeable Ca correlated negatively with extractable Zn (p<0.01), while total porosity correlated positively (p=0.01, 0.05) with all the micronutrients studied except Boron. By the USDA System, P3 was classified as Oxyaquic Hapludalf, while P1 and P2 qualified as Typic Hapludalf. P1, P2 and P3 were correlated as Chromic Luvisol (Ochric, Profondic), Rhodic Luvisol (Ochric, Loamic) and Haplic Luvisol (Loamic, Ochric, Profondic), respectively by the World Reference Base for Soil Resources System. The concentration of available Fe, Mn, Zn, Cu and B were lower than world-wide ranges and are not likely to be injurious to crops in the study area.

**Keywords:** Calcareous mudstone; Soil properties; Taxonomic Classification; Nutrients

### **Introduction**

Calcareous mudstone is a sedimentary rock and consolidated product of calcareous sands, limy mud and crushed shells (Anatale, 1996). It is composed of carbonates in the form of aragonite, calcite and dolomite as well as small amounts of iron bearing carbonates (Monroe and Wicander, 1995). The mudstone formations have been referred to as River Shale group or the oldest marine carbonate sequence which are mostly impervious shale with

minor deltaic sediments deposited during Cenomanian to Mid-Albian age (Peters, 1982). In Cross River State, mudstone is found in combination with limestone, shale and sandstone (NGSA, 2008), often referred to as marls or impure limestone (Ekwueme, 2003). Studies have shown that calcareous mudstone undergoing weathering under humid tropical environment can influence soil morphological, physical and chemical properties (Al-Farraj, 2011). The high

rainfall of the study area and soil temperature regime (Isohyperthermic) can enhance chemical weathering by predisposing the impure limestone or marl to ferrallitic or lateritic pedogenesis (Ibanga *et al.*, 2005; Ofem *et al.*, 2020).

Studies on similar soils elsewhere indicate that the soils are high in cation exchange capacity, phosphorus, near neutral in soil pH as well as low in organic carbon and nitrogen (Ibanga *et al.*, 2005). The physical properties are characterized by moderate sand, low to medium silt and high clay contents as well as moderate total porosity (Aki and Antigha, 2015). Bhattarai *et al.* (2006) observed that weathered mudstone and the soils overlying them contribute to landslide, while Ofem *et al.* (2020) observed that carbonate rich soils overlying shale-limestone and sandstone formation in higher elevations were more mature; having well-developed B horizons as well as Fe-Mn concretions and clay cutans. As much as the tropical rainforest region of Nigeria supports arable crop farming due to its high rainfall and sunshine regime, there is need for resource inventory as regards the quality of soils in the area. When ascertained through scientific processes, the problems associated with land use planning would have been half solved and land degradation reduced to the barest minimum.

Compared to soils developed on limestone which is the closest parent material to calcareous mudstone, literature is generally scanty on the soils developed on calcareous mudstone. The interest of the government and individuals is often channeled towards limestone which is of quicker economic returns and geologic

value, hence the soils overlying limestone need to be given more attention. Cross River state government is no exception to this bias. Similarly, farmers as well as researchers have shown unreserved interest on soils overlying limestone in the area (Aki and Antigha, 2015; Ofem *et al.*, 2020). Poor background information on the soils overlying calcareous mudstone has also denied farmers in the area of basic soil related information; hence cultivating soils with little or no resource inventory. Such practices may predispose the soils to high vulnerability and degradation rate. It is against this backdrop that the present study was conceived.

The soils under study support the growth of rice, cucumber, okra, oil palm, maize, plantain and banana. However, urbanization emanating from fast developing Calabar Municipality is gradually becoming a threat to agricultural activities in the area. Arable lands are gradually being consumed by industrial and residential facilities, while increasing human population exerts pressure on the available lands which strive to meet basic human needs. This has resulted in intensive cultivation of available arable lands with consequential nutrient exhaustion, hence the need for characterization and micronutrients content determination of the soils. This will further act as a guide to farmers in decision making regarding land use.

The study was therefore designed to characterize the soils based on their morphological, physical and chemical properties, as well as the relationship between these properties and soil micronutrients contents. Also, to classify the soils using the USDA System of Soil

Taxonomy (Soil Survey Staff, 2014a) and correlate with the World Reference Base for Soil Resources System (FAO, 2014).

## Materials and Methods

### Description of the study area

The study was carried out in New Netim, Odukpani LGA (5°00' and 5°15' N; 8°04' and 8°25' E) of Cross River State. The area has tropical humid climate. The climatic data are adapted from the Calabar area, since Odukpani falls with 150km range of this principal synoptic station as recommended by Ayoade (2004). The area is characterized by a mean annual temperature range of 23.53-31.95°C with mean of 27.23°C and annual rainfall range of 2,109-3,770.8mm/annum with mean of 2894.1mm/annum. Relative humidity and evapotranspiration rate have mean values of 84.99 % and 2.62 mm/annum, respectively (Sambo *et al.*, 2016). The geology of the area is mainly sedimentary and composed of nodular marlstones inter-bedded with thin beds of shales and clay in the Calabar flank (Peters, 1982), with nearly level to moderately sloping topography. The vegetation is dominantly tropical rainforest, and secondary forest regrowth in areas that have witnessed human activities like mining, agriculture and lumbering.

### Field studies

The contour map of Odukpani LGA was generated in the ArcGIS 10.8 environment and profile graph plotted out to show elevations along a vertical axis and distance on the horizontal axis as reported in Kefas *et al.* (2020). A profile pit was sunk along each elevation range to represent the highest (P1)(8°20'25.912"E, 5°7'41.034"N, 20-

27m), mid (P2) (8°20'18.114"E, 5°8'5.532"N, 20-27 m) and lowest (P3) (8°19'58.38"E, 5°8'18.27"N, 10-19 m) elevation ranges on the contours using the free soil survey technique (Fig. 1). The soil profiles were delineated and soil samples collected from pedogenic horizons beginning from the lowest horizons upwards. The soils were described following the criteria of Soil Survey Manual (Schoeneberger *et al.*, 2012). Core cylinder samples were collected vertically from pedogenic horizons and used for the determination of soil bulk density and total porosity by the procedures of Soil Survey Staff (2014b).

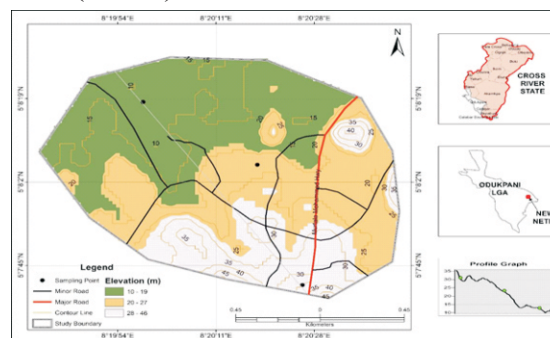


Fig. 1: Contour and profile graph of New Netim, Odukpani, Cross River State

### Laboratory studies

Soil samples meant for laboratory analyses were stored in polythene bags, labeled, transported, air dried under laboratory conditions and ground using porcelain mortar and pestle. The ground soil samples were sieved through 2 mm mesh of sieves and the fine earth fractions preserved for laboratory analyses. Soil samples meant for organic carbon and total nitrogen determinations were further sieved with a 0.5 mm sieve.

Soil particle sizes were dispersed with sodium hexametaphosphate, while size

fractions were obtained by the Bouyoucos hydrometer method (Soil Survey Staff, 2014b). Soil pH was determined in 1:2.5 soil to water using a coromel glass electrode pH meter. Soil organic carbon was determined by the Walkley and Black wet oxidation method, and total N by macro Kjeldahl digestion method as modified by Udo *et al.* (2009). Bray 1 method was used in the determination of available phosphorus, while exchangeable bases of Ca, Mg, K, and Na were determined by neutral NH<sub>4</sub>OAc displacement method and read through by atomic absorption spectrophotometer as described by Udo *et al.* (2009). Cation exchange capacity was obtained by the use of 1N NH<sub>4</sub>OAc at pH 7, while base saturation was obtained by expressing the sum of exchangeable bases as a percentage of the CEC at pH 7.

**Statistical analysis:** Descriptive statistics and correlation analysis were performed using the R software.

### Results and discussion

Morphological properties of the soils overlying calcareous mudstone are presented in Table 1. Pedons in the high (P1) and mid elevations (P2) were deep to impenetrable layers and water table (110-163 cm), while that at the lowest elevation (P3) was however, moderately deep to water table (< 60 cm). The epipedons were generally less than 15 cm in thickness and described as thin by Esu (2010). The thin epipedons may have been as a result of the dominance of erosion in the high rainfall region. This was also observed elsewhere by O'Byrne (1967) in an earlier study. Soil colour was dominantly brown (10YR, 4/3-3/2) in the epipedons of P1 and P2 with

shades of gray, dark and yellowish brown colours dominating the endopedons. Dark to brown soil colours are indicative of humus, while shades of gray may indicate poorly drained conditions. However, P3 was weak red (2.5YR 4/2), and light red (2.5YR 7/6) to pinkish white (7.5YR 8/2) in the epipedon and endopedons, respectively. Such reddish colouration in a poorly drained soil may depict the presence of Jarosites. Yellowish red mottles (5YR 5/6) were commonly obtained in the endopedons of the summit and middle slope at depths exceeding 67 cm. Sandy loam textural class dominated the entire soils and depths except in the epipedon of P1. One of the pioneer studies on soils over calcareous mudstone obtained silt loam texture in Gisborne-East Cape region and described the soils as fertile (O'Byrne, 1967). Soil structure ranged from weak to moderate, medium granular to subangular blocky structures in the endopedons. Soil consistence ranged from slightly sticky (wet) and friable (moist) in the epipedons to sticky (wet) and firm (moist) in the endopedons. Soil pores, roots, worms, ants and termites were many in the epipedons and decreased in number and size with increasing soil depth.

The physical properties of the soils are presented in Table 2. The particle size distribution was dominated by sand and silt. The sand fraction exceeded 42 % in the entire soils with comparatively higher values obtained in P3 (Table 2). Silt fraction had a range of 28.7-55.7% in the entire soils and was quite high in P1, hence the silt loam textural class. In an earlier study by Claridge (1960), 4 and 7% of sand and silt were obtained, respectively in the calcareous soils over mudstone in Waerenga-O-Kuri. In similar soils

**Table 1: Morphological properties of the soils**

Horizon	Depth Cm	Matrix colour	Mottles	Text	Struc.	Consistence (wet/moist)	Boun	Other characteristics
P1 (Highest elevation): Typic Hapludalf; Chromic Luvisol (Ochric, Profondic); ( 8°20'25.912"E, 5°7'41.034"N, 20-27m)								
Ap	0-8	10YR 4/3 (Brown)	-	Sil	2 msbk	Ss/vf	Cs	Many common and medium pores, roots. Millipedes and ants activities.
Bt1	8-67	10YR 5/2 (Grayish brown)	-	Sil	2 mcsbk	s/fr	Gs	Common medium pores, roots. Worms and termites
Bt2	67-17	10YR 5/2 (Grayish brown)	5YR 5/6 (Yellowish red)	L	3 mcsbk	s/fr	Gs	Common medium pores and roots clay cutans, worms, ants and millipedes.
Cr	117-163	10YR 5/2 (Grayish brown)	5YR 5/6 (Yellowish red)	Sl	3mcsbk	Ss/fr	-	Few medium pores, roots and ants
P2 (mid elevation): Typic Hapludalf; Rhodic Luvisol (Ochric, Loamic); (8°20'18.114"E, 5°8'5.532"N, 20-27m)								
Ap	0-10	10YR 3/2 (Brown)		Sl	2 msbk	Ss/vf	Cs	Common medium pores, few medium roots
Bt1	10-44	10YR 3/3 (Dark brown)		Sl	2 msbk	s/fr	Cw	Common medium pores, few common roots, ants and worms
Bt2	44-83	10YR 5/4 (Yellowish brown)		Sl	2 mcsbk	s/fr	Cs	Medium pores, few fine roots, ants, termites and many clay cutans
Cr	83-110	10YR 5/1 (Gray)	5YR 5/8 (Yellowish red)	Sl	2 msbk	Ss/fr	-	Common medium roots, ants and termites
P3 (Lowest elevation): Oxyaquic Hapludalf; Haplic Luvisol (Loamic, Ochric, Profondic); ( 8°19'58.38"E, 5°8'18.27"N, 10-19m)								
Ap	0-13	2.5YR 4/2 (weak red)		Sl	1mgr	Ss/f	Cw	Many medium roots
AB	13-40	2.5YR 7/6 (light red)		Sl	1msbk	Ss/fr	Cw	Many medium roots, ferrous cutans on ped faces
Bt	40-60	7.5YR 8/2 (pinkish white)		Sl	2msbk	Ss/fr	-	Few fine root and few stones, ferrous cutans on ped faces, clay cutans

elsewhere, ranges of 4-26% and 39-52% were reported for sand and silt, respectively (Bhattacharai *et al.*, 2006). There were indications of clay movement to the endopedons (presence of argillans in the B horizons).

Relatively well developed B horizon was reported in soil profiles developed over mudstone (Righi and Meunier, 1995). However, the clay content in the entire soils was quite low with values ranging from 2.3 to 11.3%. This contradicts the 89 % of clay obtained in an earlier study by Claridge (1960), 30-44% by Bhattacharai *et al.* (2006), and a recent study by Zhang *et al.*, (2020) which described similar soils as highly plastic clays characterized by fissures, mainly by virtue of its high clay amount. Furthermore, Quinta-Ferreira (2010) described the soils as silts or clays of low plasticity. Relatively higher sand content in P3 (lowest elevation) indicates the dominance of alluvium over colluvium, and

that the material may have been deposited by adjoining streams. Similarly, the gentle slope may have discouraged the rapid movement of clay by water down-hill. Furthermore, the dominance of silt over clay in the soils may be linked to poor dispersion of soil particle sizes, which may have classified 'aggregated clays' as silt. Ranges of 1.2-1.6Mg/m<sup>3</sup> and 28.3-50% were obtained for bulk density and total porosity, while particle density was within the acceptable value of 2.65Mg/m<sup>3</sup> for mineral soils in the tropics. Such bulk density values will not hinder root proliferation in the well aerated soils.

The chemical properties of the soils are presented in Table 3. Soil pH (HQ) ranged from 7.1 to 8.04 in the entire soils with values that increased with soil depth, and reflect the presence of carbonate rich bedrock. The soils were slightly to moderately alkaline by the scale of Holland *et al.* (1989). Soil organic carbon and total

**Table 2: Physical properties of the soils overlying calcareous mudstone**

Horizon	Depth Cm	Sand	Silt %	Clay	BD Mg/m <sup>3</sup>	PD	TP %
P1 (Highest elevation): Typic Hapludalf; Chromic Luvisol (Ochric, Profondic)							
Ap	0-8	42	55.7	2.3	1.3	2.08	37.5
Bt1	8-67	38	50.7	11.3	1.3	2.20	40.9
Bt2	67-17	46	43.7	10.3	-	2.14	-
Cr	117-163	48	44.7	7.3	-	2.40	-
P2 (mid elevation): Typic Hapludalf; Rhodic Luvisol (Ochric, Loamic)							
Ap	0-10	57	37.7	5.3	1.2	2.10	42.9
Bt1	10-44	52	41.7	6.3	1.3	2.00	35.0
Bt2	44-83	56	36.7	7.3	1.5	2.20	31.8
Cr	83-110	58	34.7	7.3	1.6	2.23	28.3
P3 (Lowest elevation): Oxyaquic Hapludalf; Haplic Luvisol (Loamic, Ochric, Profondic)							
Ap	0-13	67.3	28.7	4	1.21	2.42	50.0
AB	13-40	64.3	24.7	11	1.33	2.66	50.0
Bt	40-60	63.3	25.7	11	-	-	-
Mean surface		55.4	40.7	3.9	1.24	2.20	43.5
Range surface		42-67.3	28.7-55.7	2.3-5.3	1.2-1.3	2.08-2.42	37.5-50.0
Mean subsurface		53.2	37.8	9.0	1.41	2.26	37.2
Range subsurface		38-64.3	24.7-50.7	6.3-11.3	1.3-1.6	2.0-2.66	28.3-50.0

N/B: BD: Bulk density, PD: Particle density, TP: Total porosity

nitrogen decreased gradually with depth in all the pedons with ranges of 0.49-2.41 and 0.01-0.21%, respectively. Relatively higher organic carbon and total N in the epipedons is a common property in the tropical rainforest. Though it is regarded as the most influenced layer, it is also a zone of organic matter deposition. Soil organic carbon was rated low to high, while total nitrogen was low to moderate on the scale of Holland *et al.* (1989). The C:N ratios of the soils were less than 22, and indicate the dominance of mineralization over immobilization (Akpan-Idiok and Ofem, 2014).

The trend of available P was quite similar to those of organic C and total N, and had values with a range of 0.13-13.0 mg/kg in the entire soils. However, values of available P in the mid elevation (P2)

were irregular. The values were rated low in the highest (P1) and mid (P2) elevations, and moderate in the lowest (P3) elevation by the scale of Holland *et al.* (1989). The soil cation exchange complex was dominated by  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  which occupied about 46 and 21 % of the adsorption complex, respectively. Exchangeable Ca (>14.0 cmol/kg) and Mg (>2.4 cmol/kg) were rated high in P1 and P2, and moderate to low in P3 (Table 3). According to Quinta-Ferreira (2010), calcite and dolomite may be found in mudstone soils without expansive minerals. These minerals may have weathered or dissolved to enrich the soils with Ca and Mg, hence the dominance of the cations. Values of exchangeable  $\text{Ca}^{2+}$  were quite high in the Cr horizons and corroborated those of soil pH, further affirming that the bedrock is carbonate rich

**Table 3: Chemical properties of the soils overlying calcareous mudstone**

Horizon	Depth Cm	pH	OC	TN %	C/N	AP Mg/kg	Exchangeable cations				CEC	BS %
							Ca	Mg	K Cmol/kg	Na		
P1 (Highest elevation): Typic Hapludalf; Chromic Luvisol (Ochric, Profondic)												
Ap	0-8	7.3	2.41	0.21	10	2.13	14	10.6	0.13	0.11	41.0	61
Bt1	8-67	7.3	1.94	0.16	12	1.38	27.4	12.3	0.19	0.19	53.0	76
Bt2	67-17	7.5	0.62	0.05	12	0.13	58.8	2.40	0.20	0.20	74.0	83
Cr	117-163	7.6	0.88	0.07	13	0.13	61.0	3.0	0.22	0.22	76.0	85
P2 (mid elevation): Typic Hapludalf; Rhodic Luvisol (Ochric, Loamic)												
Ap	0-10	7.1	2.37	0.20	12	3.63	27.4	11.6	0.17	0.17	56.0	70
Bt1	10-44	7.3	1.74	0.15	12	1.75	20.6	17.7	0.20	0.20	47.0	82
Bt2	44-83	7.1	0.59	0.05	12	6.00	16.8	5.7	0.15	0.15	42.0	54
Cr	83-110	7.4	0.49	0.30	2	2.88	43.2	9.0	0.12	0.17	64.0	82
P3 (Lowest elevation): Oxyaquic Hapludalf; Haplic Luvisol (Loamic, Ochric, Profondic)												
Ap	0-13	7.8	1.26	0.10	13	8.37	7.06	0.40	0.12	0.08	8.5	90
AB	13-40	8.02	0.68	0.06	11	4.38	6.80	0.80	0.11	0.09	8.8	89
Bt	40-60	8.04	0.88	0.01	88	13.00	6.20	0.40	0.12	0.10	8.02	85
Mean surface		7.4	2.01	0.17		4.71	16.2	7.5	0.14	0.12	35.17	74
Range surface		7.3- 7.81	1.26- 2.41	0.10- 0.21		2.13- 8.37	7.02- 27.4	0.4- 11.6	0.12- 0.17	0.08- 0.17	8.5- 56.0	61- 90
Mean subsurface		7.5	0.98	0.11		3.71	30.1	6.4	0.16	0.17	46.6	80
Range subsurface		7.1- 8.04	0.49- 1.94	0.01- 0.16		0.13- 13.0	6.20- 61.0	0.40- 17.7	0.11- 0.22	0.09- 0.22	8.02- 76.0	54- 89

N/B: OC: Organic carbon, TN: Total nitrogen, C/N: Carbon:nitrogen ratio, AP: Available phosphorus, CEC: Cation exchange capacity, BS: Base saturation

and may have weathered to release  $\text{Ca}^{2+}$  to the soil. Similar findings were recorded by Fityus and Smith (2004) in a study on the development of a residual soil profile from mudstone. On the other hand, exchangeable K ( $<0.3\text{cmol/kg}$ ) and Na ( $<0.3\text{cmol/kg}$ ) were low in the entire soils by the scale of Holland *et al.* (1989). The cations have low adsorption capacity and may have been leached from the soils. Values of exchangeable acidity were quite low and ranged from 0.01 to 0.06cmol/kg. One would anticipate these low values as the soils are underlain by calcareous mudstone. Cation exchange capacity ( $\text{NH}_4\text{OAc}$ ) in the highest (P1) and mid (P2) elevation ranges had values that exceeded 40cmol/kg in all depths and rated very high, while its values in the valley bottom were less than 12cmol/kg, and rated low by the scale of Holland *et al.* (1989). Since both clay and organic carbon were low especially in the endopedons, it is most likely that high CEC was due to the high silt content in the soils. This assertion is corroborated by positive and high correlation of CEC with silt ( $r=0.65$ ). Irrespective of landscape position, the values of base saturation exceeded 60% and were rated high by the scale of Holland *et al.* (1989). This indicates that the exchangeable bases are most likely to be available for crop uptake.

### Soil micronutrients

The concentration of available Fe, Mn, Zn, Cu and B are presented in Table 4. Available Fe ranged from 91.2 to 162.3mg/kg, Mn had a range of 21.5-159.8mg/kg, Cu ranged from 1.78 to 3.31mg/kg, while 2.6-4.8mg/kg and 1.6-2.34mg/kg were the concentrations of available Zn and B, respectively.

In every case, values of these nutrients were comparatively higher in the top soils with a gradual decrease as soil depth increased. The values reported in this study are way lower than world-wide ranges in soils. Kabata-Pendias (2011) reported a range of 4000-10000mg/kg for available Fe in calcareous soils, while Melo *et al.* (2006) reported an average of 8.7mg/kg for limestone soils in Brazil, and a range of 14-109mg/kg for Cu in world-wide soils. Available Mn, Zn and B have been reported to have world-wide ranges of 411-550, 60-89 and 23-57mg/kg, respectively.

Correlation of these nutrients with total porosity was significant at  $p < 0.05$  and 0.01 ( $r > 0.6$ ) for every pair, except B. Fe and B had  $r > 0.5$  when correlated with organic carbon (Fig. 2); however, correlation with organic carbon was significant with only Fe ( $p < 0.05$ ). Increasing organic matter content is most likely to bring about an increase in

**Table 4: Micronutrients contents of the soils overlying calcareous mudstone**

Descriptive	Fe	Mn	Cu	Zn	B	Fe	Mn	Cu	Zn	B	Fe	Mn	Cu	Zn	B
Statistics	P1					P2					P3				
	mg/kg														
Mean	121.58	105.7	2.19	3.25	2.03	109.53	99.4	2.48	3.05	1.9	129.27	116.57	2.7	4.13	2.11
SD	29.83	56.2	0.28	0.7	0.13	16.72	8.02	0.56	0.17	0.25	29.65	51.36	0.81	0.76	0.22
SE	14.91	28.1	0.14	0.35	0.063	8.36	4.01	0.28	0.087	0.12	17.12	29.65	0.47	0.44	0.13
MIN	94.8	21.5	1.9	2.6	1.9	91.2	92.8	1.8	2.8	1.6	102.1	59.8	1.78	3.3	1.9
MAX	162.3	136.4	2.57	3.9	2.2	124.3	110.1	3.1	3.2	2.1	160.9	159.8	3.31	4.8	2.34
CV	0.25	0.53	0.13	0.21	0.062	0.15	0.081	0.23	0.057	0.13	0.23	0.44	0.3	0.19	0.1

N/B: SD: Standard deviation, SE: Standard error, MIN: Minimum, MAX: Maximum, CV: Coefficient of variation

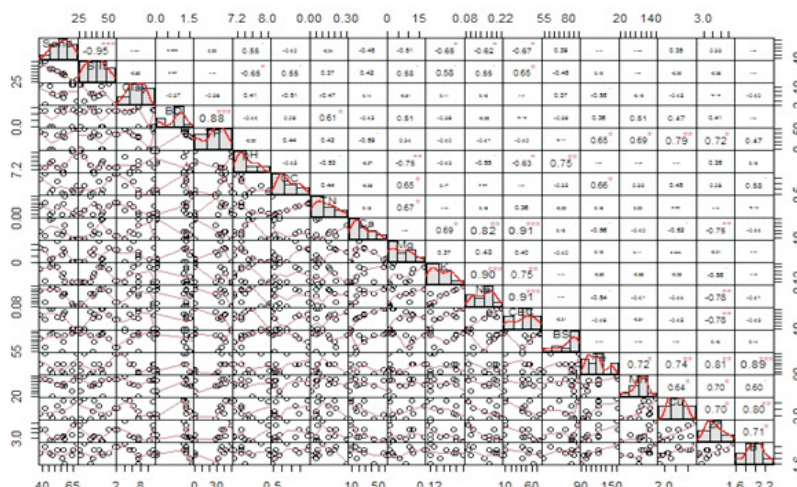


Fig. 2: Correlation matrix of soil properties and micronutrients

Fe, while increasing total porosity increases the availability of the entire micronutrients except B. High organic matter is responsible for higher micronutrients in soils (Shuman and Hargrove, 1985; Kitundu and Mrema, 2006). On the other hand, exchangeable Ca is most likely to be antagonistic with Zn availability ( $p < 0.01$ ) in the calcareous soils as negative correlation was obtained; hence, liming the soils should be avoided or carefully done for specific crops to avoid nutrient fixing. These align with earlier studies by Lee *et al.* (1997) and Kabata-Pendias (2011) who observed that sorption and desorption of trace elements in soils are regulated by organic matter. CEC also correlated negatively with Zn ( $p < 0.001$ ), and indicates decreasing Zn values when CEC is increased. However, negative correlation is obtained between trace nutrients with clay and CEC in the present study and positive relationship with organic matter.

The low world-wide levels of these nutrients indicates no soil contamination, however, all the micronutrients correlated

positively ( $p < 0.05$ ,  $0.001$ ). This indicates that high amount of Fe is most likely to increase the availability of Mn, Zn, Cu and B and contradicts findings by Kitundu and Mrema (2006) who obtained an inverse relationship and Mathew *et al.* (2016) who did not obtain any significant correlation. Low levels of Fe and Mn, especially in the humid tropical region indicates youthfulness of the soils developed over calcareous mudstone, as soils in the tropics are often high in Fe and Al, and manganese concretions (Ofem *et al.*, 2020).

### Soil classification

Base saturation (NH<sub>4</sub>Ac, pH 7.0) of the soils was more than 50 % in the argillic B horizons as well as the presence of ochric epipedons by virtue of their thickness ( $< 25$  cm). The soils qualified as Alfisols based on the criteria of the USDA Soil Taxonomy (SSS, 2014). They are characterized by an udic moisture regime and meet the requirements for an Udalf. The soils do not have a clay decrease with increasing depth of 20 % or more from maximum clay

content, have argillic B horizons but fail to meet other criteria of the great groups, and qualified as Hapludalfs. Pedon 3 (P3) is saturated with water in layers within 100 cm of the soil surface for more than 30 cumulative days, and qualified as Oxyaquic Hapludalf. P1 and P2 qualified as Typic Hapludalf in the subgroup category.

The entire soils correlated with Luvisols in the Reference Soil Group of the World Reference Base for Soil Resources System (FAO, 2014). In the second level of the WRB classification, P1 (highest elevation) qualified as Chromic Luvisol (Ochric, Profondic), while P2 (mid elevation) was Rhodic Luvisol (Ochric, Loamic) and P3 (lowest elevation) was Haplic Luvisol (Loamic, Ochric, Profondic).

### Soil management

Though the soils were relatively optimum in nutrients except for the micro nutrients that were below world-wide levels, it is necessary to protect the thin surface soils which accommodates majority of the nutrients from agents of erosion in the high rainfall zone. This may be done through a boost in the organic matter content by mulching with plant residues and cover crops, and by the introduction of practices such as zero tillage farming across slope. This will invariably, increase the soil organic carbon, total N and available P content of the soils and provide the soil with good soil structure.

### Conclusion

The morphological, physical and chemical properties, as well as their relationships with micronutrients in the soils overlying

calcareous mudstone was studied and classified. The soils were moderately deep and brown with shades of gray, dark and yellowish brown colours in the endopedons. Soil texture was loamy with clear dominance of silt and sand over clay, while bulk density values were less than 1.6g/cm<sup>3</sup>. The soils were slightly to moderately alkaline in pH, while exchangeable Ca and Mg dominated the soil exchange complex with moderate to high values that exceeded 14.0 and 2.4cmol/kg, respectively. Carbon:nitrogen ratio indicated the dominance of mineralization over immobilization. The concentration of available Fe, Mn, Zn, Cu and B were lower than world-wide ranges and are not likely to be injurious to crops in the study area. Nutrient content will therefore support the cultivation of most arable crops. Only Fe and B correlated positively and highly with organic carbon and may be injurious to crops if soil organic matter accumulation is encouraged. On the other hand, exchangeable Ca and clay correlated negatively with the micronutrients. Liming the soils should therefore be avoided or done with care. The soils qualified as Alfisols and correlated with Luvisols.

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